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Reference Points for Scallop Fisheries in the Maritimes Region

Niveaux de référence – pêche au pétoncle, région des Maritimes

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ABSTRACT

The fisheries for sea scallops (*Placopecten magellanicus*) in the Maritimes Region are managed geographically as offshore fisheries (Georges, Browns, German, Sable, Western and Middle Banks) and inshore fisheries (Bay of Fundy and approaches, Scallop Fishing Area (SFA) 29 West). While population models are used for determining stock status for many of the scallop areas, the lack of evidence for stock/recruitment relationships necessitates determining reference points for the precautionary approach using empirical methods. Model-based estimates of population biomass and fisheries exploitation rates are used to determine biomass and removal reference points, respectively. The offshore fisheries were awarded certification by the Marine Stewardship Council (MSC) in 2010 and have established limit reference and upper stock reference points as 30% and 80% of the mean biomass over the period 1981 to 2009. The target removal exploitation rate for Georges Bank was set at 0.25. The inshore fisheries will be reviewed by MSC in 2012 and are looking at the proposal to set the limit reference point to the lowest biomass that the stocks have recovered from. The upper stock reference point will need to be set so that management has time to reduce exploitation to avoid having the biomass drop below the lower reference point. Methods for defining reference points for areas where model estimates are not available were briefly discussed. Recent research on spatial considerations for reference points was introduced.

RÉSUMÉ

La pêche au pétoncle géant (*Placopecten magellanicus*) dans la région des Maritimes est gérée sur le plan géographique comme une pêche hauturière (banc de Georges, banc de Brown, banc German, banc de l'île de Sable, banc Western et banc du Milieu) et une pêche côtière (baie de Fundy et ses environs, zone de pêche du pétoncle 29 ouest). Bien que des modèles de population soient utilisés pour déterminer l'état des stocks d'un grand nombre de zones de pêche du pétoncle, le manque de preuves relativement aux relations stock-recrutement fait en sorte qu'il faut déterminer des niveaux de référence à l'aide de méthodes empiriques pour l'approche de précaution. Les estimations de la biomasse de la population basées sur des modèles ainsi que les taux d'exploitation de la pêche sont utilisés pour déterminer les niveaux de référence relativement à la biomasse et à l'exploitation. La pêche hauturière a obtenu une certification de la Marine Stewardship Council (MSC) en 2010. Un niveau de référence limite ainsi qu'un niveau de référence supérieur de 30 % et 80 % respectivement de la biomasse moyenne, pour la période allant de 1981 à 2009, ont été fixés. Le taux d'exploitation cible pour le banc de Georges a été fixé à 0,25. La pêche côtière sera examinée par le MSC en 2012 selon la proposition voulant que le niveau de référence limite soit fixé au niveau de biomasse le plus faible à partir duquel les stocks se sont rétablis. Le niveau de référence supérieur du stock devra être établi afin que les responsables aient suffisamment de temps pour diminuer l'exploitation afin d'éviter que la biomasse descende sous le niveau de référence inférieur. On a discuté brièvement des méthodes servant à l'établissement des niveaux de référence dans les zones pour lesquelles il n'existe pas d'estimations de modèle. On a présenté les recherches récentes sur les considérations spatiales relatives aux niveaux de référence.

INTRODUCTION

The Department of Fisheries and Oceans (DFO) policy[1] on the application of the precautionary approach to fisheries management includes the use of reference points linked to stock and ecosystem indicators. The policy states that these reference points will usually be determined using standard biomass and harvest metrics (e.g., fishing mortality or exploitation). If these metrics are not available then some other measure related to the productive potential and harvest should be used so that the objective of avoiding serious harm to reproductive capacity of the stock can be realized.

For the case where biomass is used, reference points are to be defined for the biomass level below which reproductive capacity will be impaired (Limit Reference Point, or LRP), at a biomass level below which removals must be progressively reduced in order to avoid reaching the LRP (Upper Stock Reference, USR) and a removal reference point indicating the maximum harvest rate (as fishing mortality or exploitation). To comply with the terms of the United Nations Fishing Agreement (UNFA)[2], this rate must be less than that associated with the maximum sustainable yield (e.g., F_{MSY} or E_{MSY} if exploitation rate used). A target biomass reference point (TRP) is a required element of UNFA and can be set equal to or greater than the USR. The recommended levels for the LRP and USR biomass reference points in the DFO policy are 40% and 80%, respectively, of the biomass that results in the maximum sustainable yield (B_{MSY}).

Estimates of B_{MSY}, F_{MSY}, or E_{MSY} can be obtained from a number of population models generally used to assess fish stocks (e.g., surplus production, delay-difference, Virtual Population Analysis (VPA)/Adapt) together with models for the relationship between spawning stock size and the amount of recruitment expected from this spawning stock (commonly the Beverton-Holt spawner-recruit model). In the absence of a model, B_{MSY} could be estimated as the average biomass (or index of biomass) over a productive period or the biomass corresponding to 50% of the maximum historical biomass.

However the estimates are obtained, the underlying concept requires first defining surplus production at any level of biomass as the difference between the biomass added to the population through growth and recruitment of young to the fishery, and the biomass removed by natural mortality. Then, at any level of biomass a sustainable catch is defined such that it removes less than or equal to the biomass added as surplus production. In addition, there is a level of biomass where the stock is most productive such that the maximum sustainable catch is produced (B_{MSY}). This latter element arises as a consequence of assuming the rate of surplus production decreases as biomass increases due to the consequent decline in food, space, etc., available to the population. When the population is at its maximum (B_0), growth plus recruitment is exactly balanced with mortality so that zero surplus production is available. For the basic logistic model of population growth, B_{MSY} is equal to one-half B_0.

The fisheries for sea scallops (*Placopecten magellanicus*) in the Maritimes Region are managed geographically as offshore fisheries (Fig. 1: Georges, Browns, German, Sable, Western and Middle Banks) and inshore fisheries (Fig. 1: Bay of Fundy and Approaches (Scallop Production Areas [SPAs] 1A, 1B, and 3–6), Scallop Fishing Area [SFA] 29 West). Total landings for 2011 were 5557 t and 1056 t, respectively. Many of the major components of these fisheries are

[1]http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm.
[2]United Nations, Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks. Sixth Session, New York, 24 July–4 August, 1995, Article 6 and Annex II.

modelled using a Bayesian state-space delay-difference population model (e.g., Smith et al. 2012, Hubley et al. 2011) that is used to estimate population biomass, recruitment (to the fishery), exploitation rate and provide advice on future catch levels. Recruitment in the model comes directly from observations from annual stock surveys instead of a spawner/recruit model. Spawner/recruit models have rarely been successfully developed for scallop species and it is likely that recruitment success may be determined more by favourable environmental conditions than by stock size for scallops (Smith and Rago 2004, Orensanz et al. 2006).

Given the lack of a usable spawner/recruit relationship, reference points for scallops will need to be determined directly from the biomass and exploitation rate estimates for those fisheries that have population models. In this paper, work to date on estimating biomass-based reference points is presented. The offshore fisheries were certified in 2010 by the Marine Stewardship Council (MSC) and the fishing industry developed a precautionary approach complete with reference points based on model-based estimates of biomass and exploitation to meet the first year conditions of their certification. These will be presented here for information. Development of biomass-based reference points for the inshore fisheries have been more problematic, but, in a recent meeting with the industry, an interim approach was agreed upon. The Full Bay Scallop fleet has applied for MSC certification of the inshore fisheries starting in 2012, and reference points will be required before the certification review is completed. Longer-term plans on developing reference points for fisheries without models and the incorporation of spatial patterns in productivity will also be discussed here.

SURPLUS PRODUCTION

Before estimating B_{MSY} by average biomass or some proportion of maximum biomass, there needs to be some evidence in the surplus production estimates that a biomass associated with maximum production exists. Surplus production (SP_t) was estimated for each year (t) for the fisheries in the inshore and offshore areas where the delay-difference model has been used as,

$$SP_t = B_{t+1} - B_t + C_t$$

where B_t and C_t refer to the estimated population biomass of commercial size scallops and catch in tonnes of meats for year *t*, respectively. Patterns of surplus production for the Bay of Fundy (Scallop Production Areas [SPAs] 1A, 1B, 3, and 4) were quite similar with large increases in biomass due to episodic recruitment (e.g., SPA 1A, 2001 to 2002), low and even negative surplus production at the resultant large biomass levels, and highly variable surplus production otherwise (Fig. 2). SPA 4 has the longest time series available starting in 1983, and this area experienced two episodic recruitment events during that time period (Fig. 2D). In the first event, the 1984 year-class was evident in the 1987 surplus production estimate followed by the smaller but still very strong 1985 year-class in 1988. The decline in biomass from 1988 to 1989 was partly due to high exploitation but also due to a major natural mortality event that appeared to occur after the fishery closed in April 1989 (Smith and Lundy 2002). High levels of natural mortality continued into 1990. In the second recruitment event, the 1998 year-class began to be picked up by the survey in 2000 as it experienced higher than average growth and was fully recruited to the fishery by 2002. Thereafter, surplus production continued to be negative until 2005 after which this year-class was essentially fished out. Unlike the situation for the 1984/85 year-classes, there was no evidence in the survey catches of clappers (paired empty shells) to indicate a similar episodic mortality event.

Similar patterns appear for Georges and Brown's Banks, that is, highly variable surplus production, large increases in surplus production due to episodic recruitment and negative

surplus production as the large year-classes are being fished down (Fig. 3). Recent levels of biomass in the Georges Bank fishery have been higher since 1999 due to large year-classes recruiting in 2001 and 2008, in addition to lower exploitation rates relative to the earlier years (Fig. 4). However, variable surplus production continues even at these higher levels of biomass.

It is possible that the size of the large year-classes may result in the scallop populations exceeding the carrying capacity of their habitat and that this effect continues on past their recruitment into the fishery. Another possibility could be that a significant amount of incidental mortality (scallops damaged by gear but not caught) could be occurring. Caddy (1973) reported that incidental mortality was equivalent to fishing mortality for the offshore dredge based on diver observations. More recently, an estimate of 20% of landed fishing mortality on Georges Bank, and 10% in the Mid-Atlantic are used for American stock assessments of scallops (D. Hart, pers. com.). The differences between Caddy's estimate and those used in the assessment are due to recent estimates of dredge efficiency being much higher than those originally used by Caddy.

The variable surplus production and lack of evidence for a biomass level *sensu* B_{MSY}, associated with a maximum surplus production is problematic for applying the DFO precautionary approach policy for two reasons. Firstly, an associated F_{MSY} can not be identified for the removal limit and, secondly, an LRP and USR can not be identified as a function of either B_{MSY} or B_0. Further, given the negative productivity associated with the highest levels of biomass observed, it is unlikely that these would coincide with B_0. Finally, the occurrence of episodic recruitment with subsequent low and even negative surplus productivity suggests that these events may need to be managed differently than when between such events. In the following section, the different approaches accepted or proposed to deal with these issues for offshore and inshore scallop are presented.

REFERENCE POINTS

OFFSHORE SCALLOP

As required for the first annual audit of their MSC certification, the offshore scallop fishing industry proposed a precautionary approach framework in February 2011 using proxies for biomass-based reference points for the most important fishing area, Georges 'A' (Fig. 1). Consistent with the DFO policy, the industry set B_{MSY} equal to the mean biomass (1981 to 2009) from the delay-difference model. The USR was set at 80% of B_{MSY} and 30% of B_{MSY} was used for the LRP[3].

The industry proposal also defined the mean exploitation of 0.25 as a removal target. This rate is very close to the 0.27 reported by Jonsen et al. (2009) as the exploitation rate that resulted in no change in biomass (1981 to 2007). This definition of a removal reference, along with the biomass reference points mentioned above, are then used to construct a Harvest Control Rule (HCR) with healthy, cautious and critical zones defined (Fig. 5). It is important to note that when reference points are defined, the emphasis should be on the approach or method used over the actual values proposed. At least one reason for this is that estimates of biomass may change from year to year with changing definitions of survey area or as new information is added to the assessment. The range of years used in Figure 5 correspond to those years used in the current assessment and differ from the range used for the MSC certification.

[3] Thirty percent (30%) of B_{MSY} corresponds to the biomass level for 50% MSY assuming the Schaeffer model for surplus production (NAFO 2004).

The industry also proposed actions to be taken when biomass was in a given zone:

- When biomass is above the USR:
  - Measures should promote the fully-recruited biomass remaining above the USR.
  - The target exploitation rate will be 25% of fully recruited biomass. Above the USR point there is flexibility in increasing the exploitation rate.
  - The TAC can be increased despite projected decline in the biomass, provided it is not expected to reduce the fully recruited biomass significantly below the USR.
- When biomass is between the LRP and the USR:
  - Measures should generally promote the rebuilding of biomass towards the USR, subject to natural fluctuations that may be expected to occur in biomass and survey results.
  - The Total Allowable Catch (TAC) should not be increased if this can reasonably be expected to result in decline trend in the fully recruited biomass.
- When biomass is below the LRP:
  - Measures must explicitly promote an increase in the biomass.
  - The exploitation rate must be in the context of a rebuilding plan.
  - If the stock falls below the proxy LRP, research may be undertaken to better determine the true LRP for this stock, the level below which reproductive success would be seriously impaired.

These measures fall into the broad scope of the precautionary approach though more consideration could potentially be given as to how exploitation should be adjusted in the cautious zone. In such cases, information concerning incoming recruitment should be considered. With respect to the other offshore Scallop Fishing Areas, only Browns North has a model for which the above approach could be adapted (Fig. 1). In other areas information is either not suitable for constructing a model at present (e.g., German) or the current fishery that has little impact on the population (e.g., Sable).

Using the approach laid out for Georges 'A' above a precautionary approach framework for Browns North could be as follows:

- USR defined as 80% mean biomass over a productive period (7281 t from 1991-2010).
- LRP defined as 30% mean biomass (2730 t, which corresponds to lowest biomass observed, 1991).
- Removal reference defined as exploitation level that results in no change in biomass (0.1, see Fig. 6)[4].

These reference points could then be used to construct a candidate HCR (Fig. 7).

[4] Different values for the exploitation level where biomass does not change reflect different productivities between fishing areas.

INSHORE SCALLOP

The current context for scientific advice on catch levels for scallop production areas where models were used is in terms of a reference exploitation rate of 0.15, and whether or not the proposed catch would result in a decrease in biomass from the current year. The main goal for this approach was to promote stability in the population biomass until recruitment levels had improved. Recruitment success seems to be determined more by favourable environmental conditions than stock size for scallops in this area. The exploitation rate "target" was determined by comparing exploitation rates and resulting biomass (either model-based or survey estimated) changes for the historical data. Biomass levels tended to increase after a fishery where the exploitation was 0.15 or less, while these levels decreased at higher exploitation rates, excluding high recruitment years.

Taking SPA 4 as an example, the surplus production rate (surplus production divided by biomass) tends to be between 0 and 0.5 for those years not affected by a large recruitment (Fig. 8). Note the decline to negative productivity after the two major recruitment events. While the mean surplus production rate between the bounds of 0 and 0.5 was 0.2, close to the 0.15 exploitation rate target given above, exploitation rates at 0.2 and higher have always led to declines in biomass.

The default values from the DFO policy for the LRP and USR biomass reference points of 40% B_{MSY} and 80% B_{MSY}, respectively, where, B_{MSY} = 50% B_0, were applied to the SPA 4 example (Fig. 9). Exploitation rates have been often been above 0.15 resulting in biomass levels falling below the LRP into the critical zone by these criteria. Once in this zone, the exploitation rate drops to average around 0.15 or so and biomass levels remain low and stable until a large recruitment event moves the biomass above the USR. Application of these criteria would result in a harvest control rule where fishing would mainly occur during high recruitment events. Note that at a mean surplus production rate of 0.2, it would take more than 14 years for the population to double at an exploitation rate of 0.15 in the absence of strong recruitment. Plainly, the surplus production time series does not support there being a unique B_{MSY} equal to one half or any other proportion of B_0. Unlike the case for Georges Bank there is not enough experience in this fishery with mid-range biomass levels (above 1000 t) except when a strong year-class is present.

An alternative approach to setting biomass-based reference points has been discussed with representatives of the fishing industry that should still fit within the policy. Given that the LRP should correspond to the impact of fishing on reproductive success, a precautionary limit could be the lowest biomass level that the stock has recovered from. The possible choice of such a limit is discussed in the policy and for SPA 4 would correspond to a biomass of 482 t. This also corresponded to a mean commercial catch rate of 7.5 kg/h which would be uneconomical at present given today's fuel and other costs (2011 biomass = 656 t with catch rate of 18.6 kg/hr). Guidance on setting an USR would be more a function of setting a biomass level high enough so there is enough time for management actions be taken such that reaching the LRP is avoided. The SPA 4 catch for the 2010/2011 fishing year was 136 t. Assuming a mean surplus rate of 0.20, a beginning of year biomass of at least 680 t would be required to avoid a decline in biomass to support this catch. Setting the USR at this level will not give the fishery much leeway in dealing with a low growth situation or any other uncertainties that may be associated with the advice for the upcoming year. If the stock experiences one year of low net growth, say 0.1, then the following year biomass will be below the USR and only 130 t above the LRP. A rebuilding plan to move the biomass to be above the USR could take between 1 and 3 years for the case of no fishing given the range in surplus production rates for this population. Reduce exploitation by half and it could take between 1 and more than 10 years to get to the USR.

Discussions will continue with industry and fisheries management on determining criteria for setting the USR.

As noted earlier, large recruitment events are usually followed by years of low or negative productivity. Similar to the Georges Bank situation, the proposal here is to allow exploitation rates to increase when these strong year-classes recruit to the fishery as a function of how many years the higher catches are expected to last, but the degree of increase in exploitation rate would be contingent on not allowing the biomass to drop below the USR.

FURTHER WORK

Models have not been developed for SPAs 5 (Annapolis Basin) and 6 (Grand Manan, Fig. 1), and stock assessments are primarily based on commercial catch rates in addition to survey trends for the latter area. For the modelled areas, catch rates are highly correlated with biomass (and survey) estimates (e.g., SPA 4, Fig. 10) and it may be possible set LRPs and USRs based on the catch rate series (e.g., DFO 2010). Discussions with the industry and fisheries management will be needed on this option.

The scallop fishery in SFA 29 West began in 2001 (Fig. 1) and the population biomass has been fished down from very high levels (Fig. 11). As a result, the time series of catch rates and biomass estimates from the surveys contain little information on the range of potential productivity or on what the lowest biomass level for stock recovery could be used to set the LRP.

This area has been the focus of spatial/habitat research following the completion of the joint Industry, NRCan and DFO multibeam project in 2005 (DFO 2006, Smith et al. 2009, Tremblay et al. 2009, Todd et al. 2012). Recent work has concentrated on identifying scallop habitat based on metrics derived from the multibeam bathymetry and backscatter and image surveys (Brown et al. 2012). Comparison of the spatial patterns of fishing intensity based on Vessel Monitoring System (VMS) data with scallop habitat suitability indicates a strong relationship (e.g., SFA 29 D, Fig. 12) as does comparison with annual survey catch per tow of commercial size scallops (Fig. 13). Trends of densities (ton/m^2) for survey biomass estimates and catch data by low (0.0–0.3), medium (0.3–0.6), and high (0.6–1.0) scallop habitat suitability indicates that the highest densities for both occur in the higher suitability areas and fishing tends to level out the densities over all areas (Fig. 14).

The trend of increasing decline in densities from the higher suitability areas evident in Figure 14 follows the predications of the stages of the spatial impact of a fishery on a population given in Caddy (1998) with the condition of similar densities everywhere corresponding to his third stage. The fourth and final stage corresponds to fishing out of key areas with continuing declines in commercial catch rate. The observed trend in decreasing densities as a function of habitat also follows that predicted by basin model for a sedentary species (McCall 1990).

Preliminary calculations of intrinsic growth rates by ranges of habitat suitability using the basin model are presented in Table 1. Surplus production will be a function of habitat suitability and the overall production rate of the stock will depend on how much biomass is available in each of the habitat types. In all of the subareas in SFA 29, the area of the medium suitability habitat tends to be much larger than that for the high suitability areas. The higher productivity areas will tend to be overfished resulting in an overall production rate closer to that of the medium suitability areas. Given the patchiness of the habitat suitability areas it is unrealistic to manage by areas of productivity. Current work is concentrating on using a combination of productivity,

density, and area to identify LRP and USR reference points that could be used for the scallops in this area, and eventually the other areas being managed.

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Table 1: Intrinsic growth rates estimated from the basin model by scallop habitat suitability range for the three major subareas in SFA 29.

Habitat	Subarea		
Suitability	29B	29C	29D
Low	0.09	0.16	0.07
Medium	0.15	0.22	0.11
High	0.29	0.38	0.27

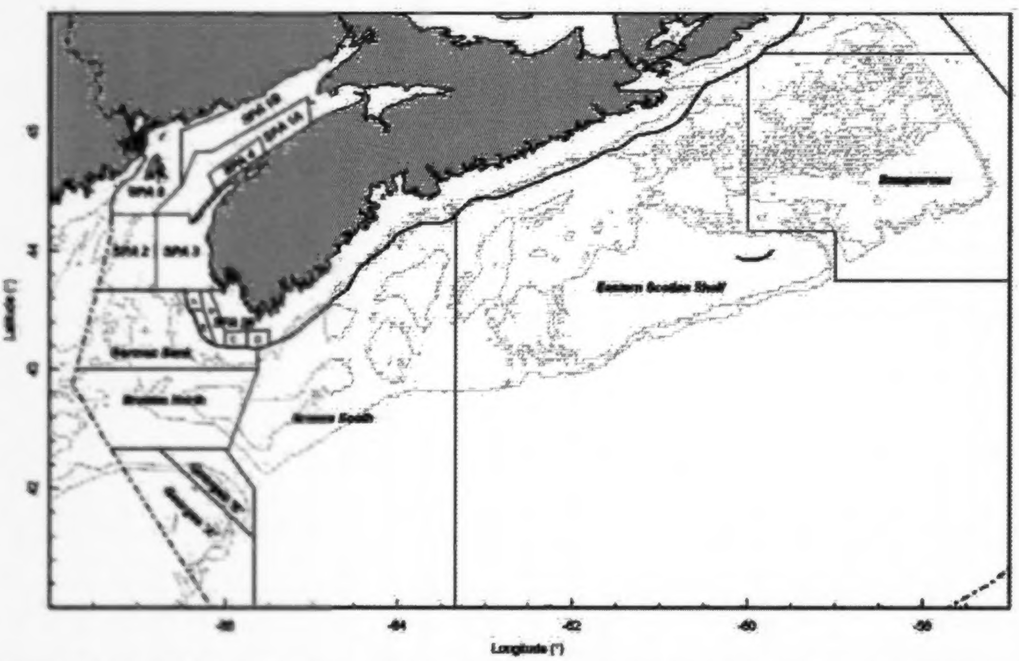


Figure 1: Scallop Fishing Areas (SFAs) and Scallop Production Areas (SPAs) in the Maritimes Region.

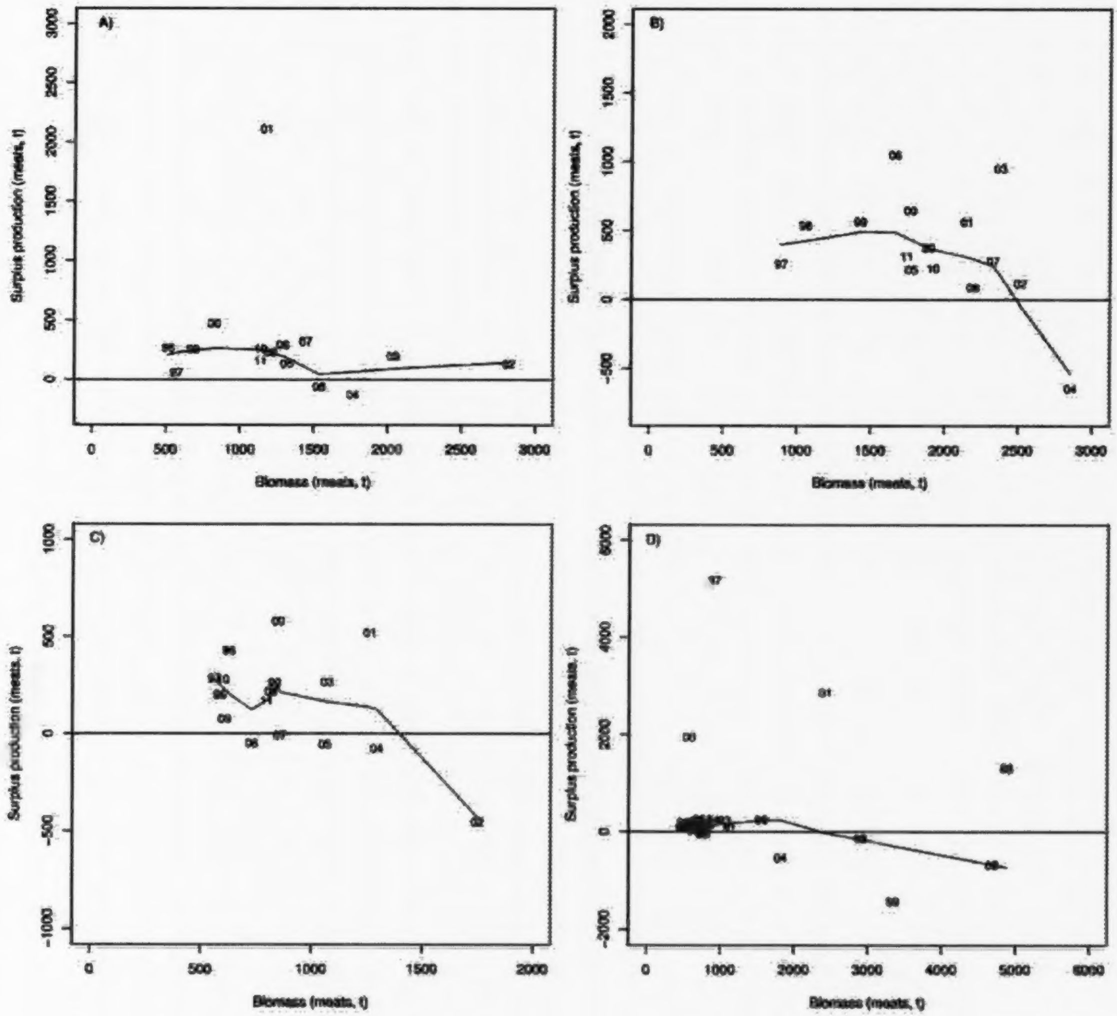
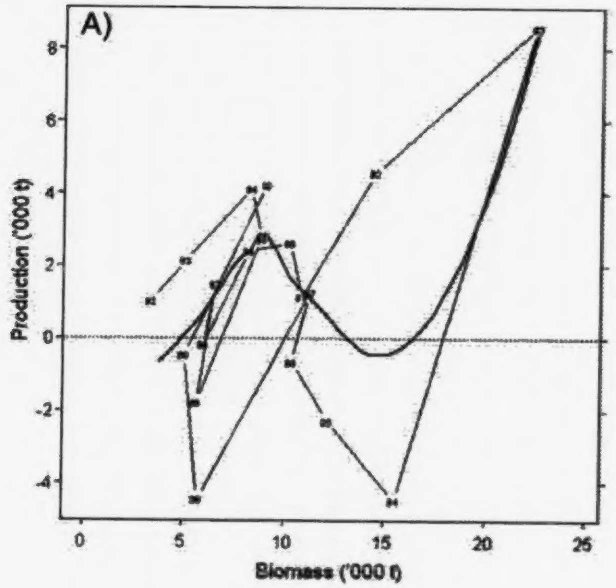


Figure 2: Surplus production for Bay of Fundy fishing areas A) SPA 1A, B) SPA 1B, C) SPA 3, D) SPA 4. Labels refer to year of the survey and biomass was estimated by the delay-difference model. Loess curve added to detect trend.



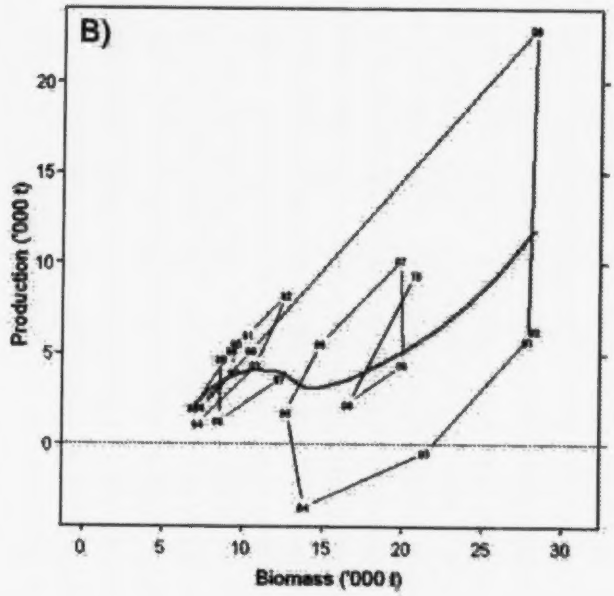


Figure 3: Surplus production for A) Browns and B) Georges Bank. Labels refer to year of the survey and biomass was estimated by the delay-difference model. Loess curve added to detect trend.

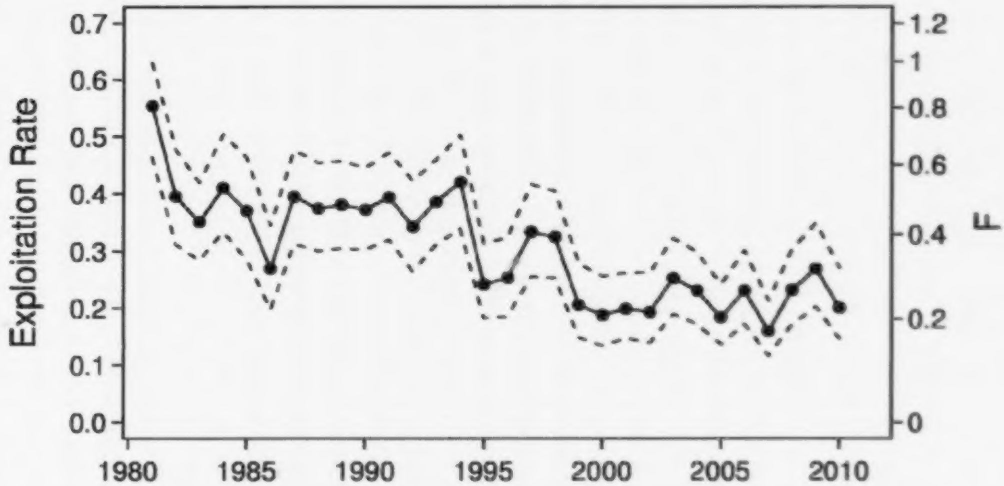


Figure 4: Exploitation rates and fishing mortality (F) trends in the Georges Bank scallop fishery.

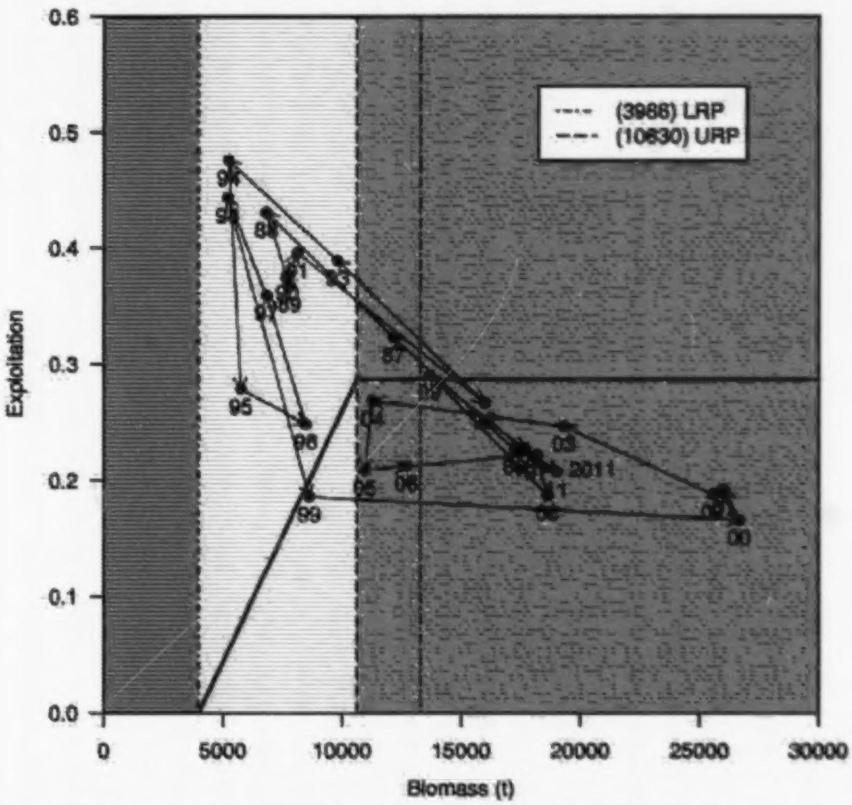


Figure 5: Reference points and harvest control rules for scallop on Georges Bank based on the Marine Stewardship Council (MSC) accepted proposal from the offshore scallop industry.

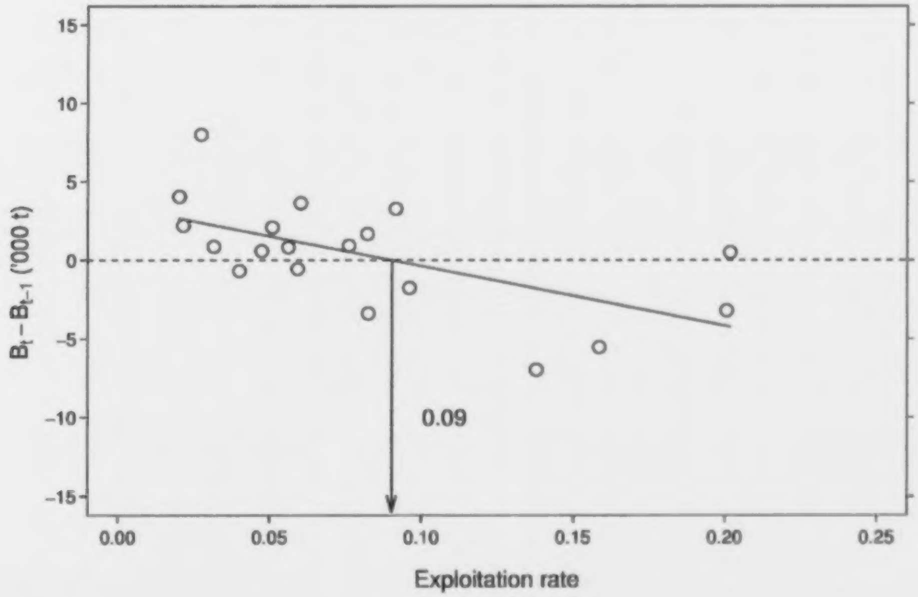


Figure 6: Change in estimated biomass (fully-recruited) versus exploitation rate for Brown's Bank. The removal reference point, i.e., the exploitation rate that results in no change in biomass, is indicated by the vertical arrow.

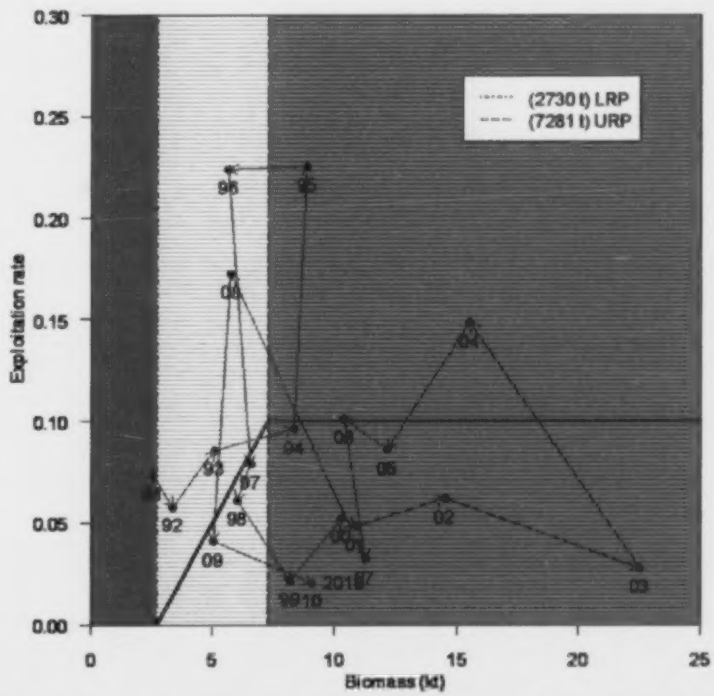


Figure 7: Proposed reference points and harvest control rules for scallop on Brown's Bank based on the MSC accepted rules for Georges Bank.

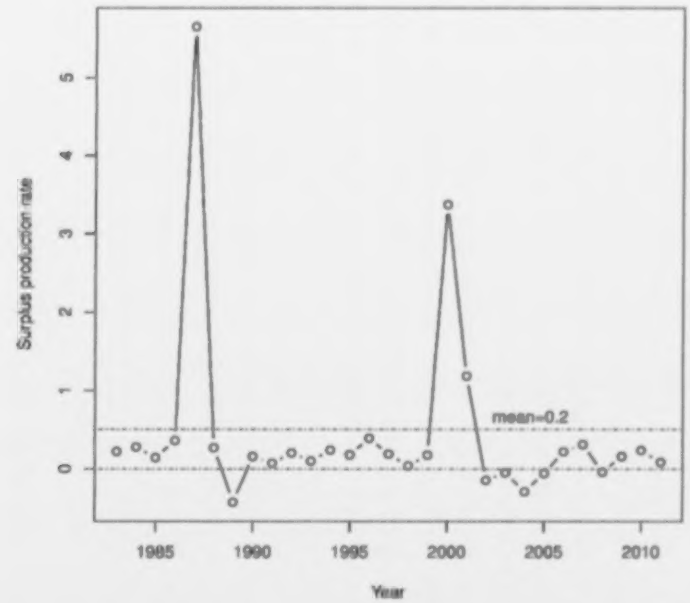


Figure 8: Surplus production rate (surplus production divided by biomass) over time for SPA 4. Horizontal dashed-dotted lines indicate bounds of 0 to 0.5. The mean surplus rate of 0.2 refers to those estimates within these bounds.

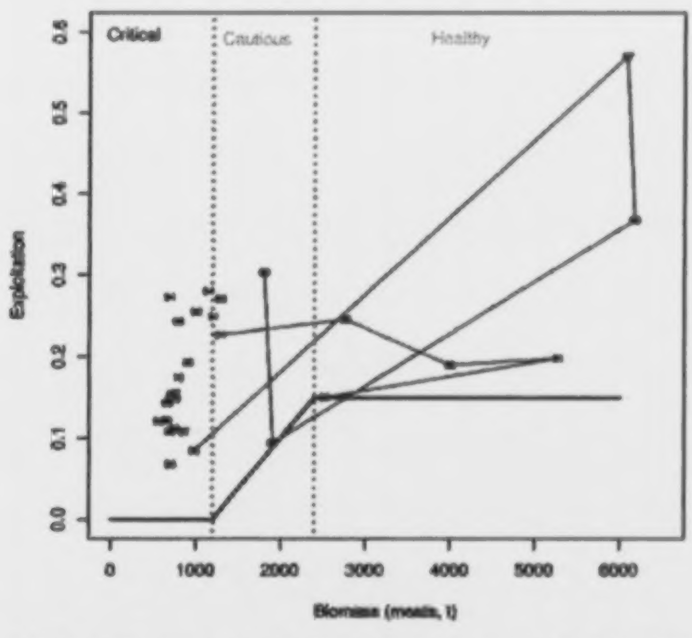


Figure 9: Application of the suggested DFO reference point system with B_0 estimated as the maximum biomass observed, B_{MSY} = 50% B_0 and LRP and USR set to 40% B_{MSY} and 80% B_{MSY}, respectively. The removal reference point is set to an exploitation rate of 0.15 (see text). Points are labelled by the year where, for example, 01 refers to 2001 corresponding to the 2001/2002 fishing season.

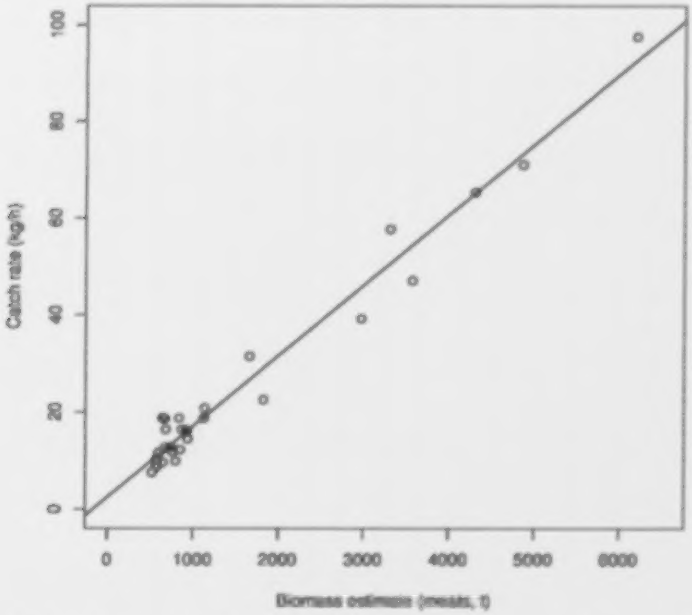


Figure 10: Commercial size biomass estimated from delay-difference population model in year t versus commercial catch rate in year t+1 for scallops in SPA 4.

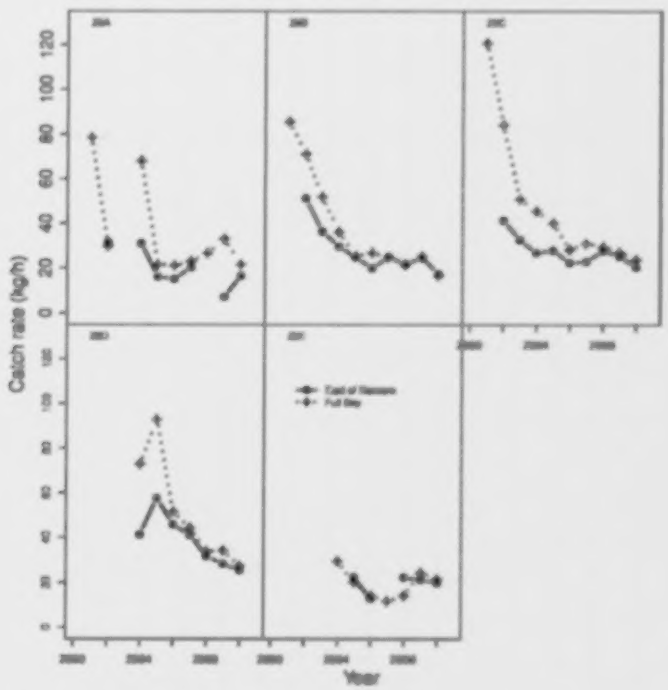


Figure 11: Annual trends for average commercial catch rate (kg/h) for SFA 29 scallop fishery for each subarea by fleet.

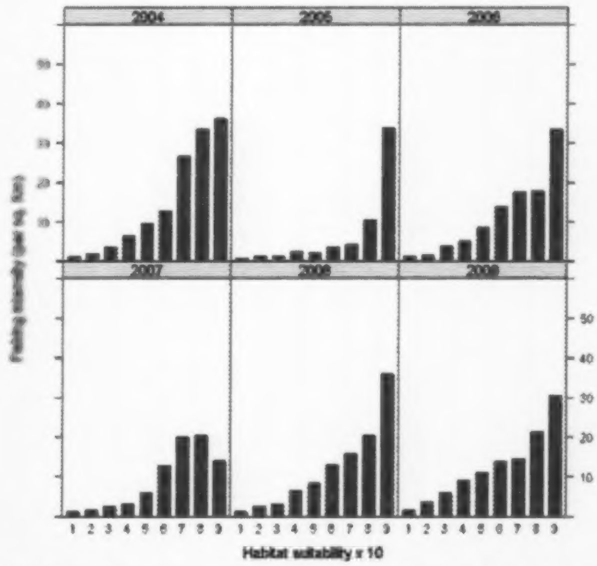


Figure 12: Fishing intensity (pings per sq. km) for SFA 29 D from Vessel Monitoring System (VMS) records compared with scallop habitat suitability. Note results are preliminary until the full analysis of VMS records has been completed.

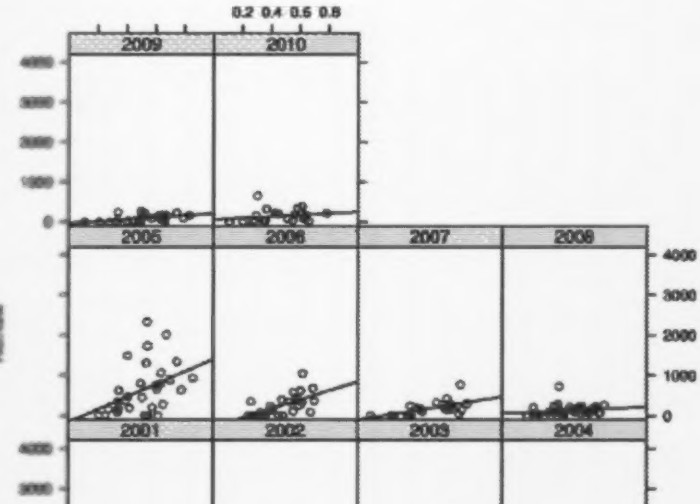


Figure 13: Scallop survey abundance (no./tow of scallops with shell heights > 100 mm) compared with scallop habitat suitability by year for SFA 29 D. This area was closed to fishing for 2001 to 2003 to wait for a large year-class to recruit to commercial size. There were limited openings in 2004 and 2005 with the whole area open to fishing starting in 2006. Note that the survey occurs after the fishery each year.

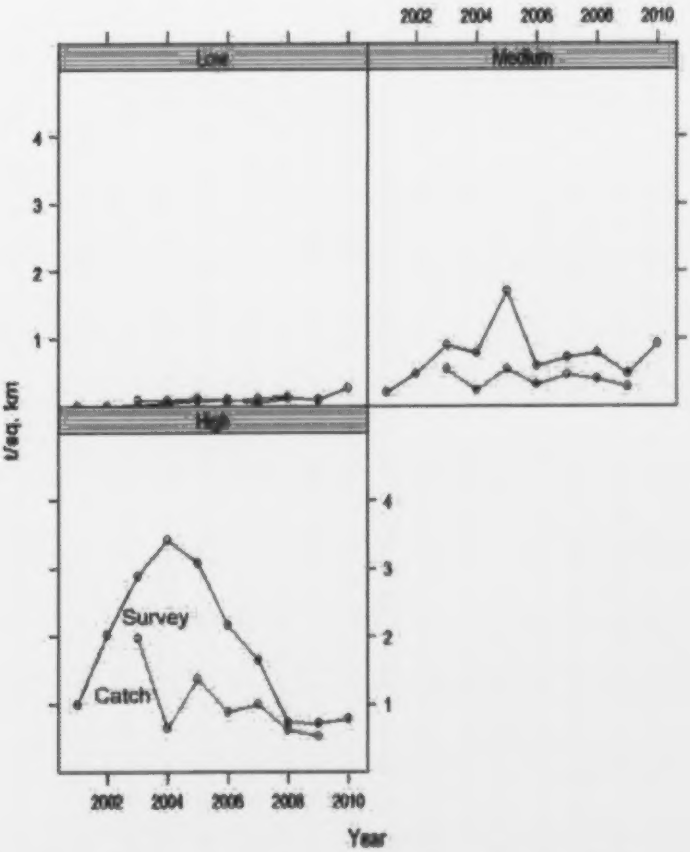


Figure 14: Survey biomass and catch (lagged one year earlier to line up with the post-season survey) expressed as density (ton/m^2) for SFA 29D. Scallop habitat suitability categorized as low (0.0–0.3), medium (0.3–0.6), and high (0.6–1.0).